

Quarkonia production in the STAR experiment

Barbara Trzeciak for the STAR Collaboration¹

*Faculty of Physics, Warsaw University of Technology
Koszykowa 75, 00-662 Warsaw, Poland*

Abstract

In this proceedings the recent STAR results of J/ψ and Υ production in $p + p$, $d + \text{Au}$ and $\text{Au} + \text{Au}$ collisions at $\sqrt{s_{NN}} = 200$ GeV at mid-rapidity are reported. J/ψ p_T spectra in $p + p$ and $\text{Au} + \text{Au}$ collisions for both low and high p_T are shown. J/ψ nuclear modification factor (R_{AA}) in $d + \text{Au}$ and $\text{Au} + \text{Au}$ collisions and Υ R_{AA} in $\text{Au} + \text{Au}$ collisions are reported. Also, J/ψ polarization in $p + p$ collisions and J/ψ v_2 for semi-central $\text{Au} + \text{Au}$ collisions are presented.

1. Introduction

The suppression of quarkonia (charmonia and bottomonia) production in high energy nuclear collisions relative to $p + p$ collisions, due to the Debye screening of the quark-antiquark potential, was proposed as a signature of the formation of QGP [1]. However, there are other effects that may affect the observed quarkonia production. The cold nuclear matter effects, e.g. nuclear shadowing, Cronin effect, nuclear absorption, can be tested in $p + A$ or $d + A$ collisions. The other hot nuclear effects, such as recombination of quark-antiquark pairs might be also present. The interpretation of the quarkonia modification in QGP requires also understanding of the quarkonia production mechanism in $p + p$ collisions. At RHIC energies the Υ meson is a cleaner probe comparing to J/ψ due to negligible contributions from $b\bar{b}$ recombination and non-thermal suppression from co-mover absorption. Measurements of the quarkonia production in different colliding systems, centralities and collision energies are needed to understand those effects. In this proceedings results on J/ψ production in $p + p$, $d + \text{Au}$ and $\text{Au} + \text{Au}$ collisions and Υ production in $p + p$ and $\text{Au} + \text{Au}$ collisions via the dielectron decay channel at mid-rapidity at $\sqrt{s_{NN}} = 200$ GeV in the STAR experiment are presented.

2. J/ψ production and polarization in $p + p$ collisions at 200 GeV

Figure 1 shows J/ψ transverse momentum spectrum in $p + p$ collisions from year 2009. The new STAR result covers a broad p_T region ($0 < p_T < 14$ GeV/c). The plot also shows predictions from various J/ψ production models. The Color Evaporation Model (CEM) [3] for prompt J/ψ can describe the p_T spectrum reasonably well. NLO Non-Relativistic QCD (NRQCD) calculations with color-singlet (CS) and color-octet (CO) transitions [4] for prompt J/ψ match the data for $p_T > 4$ GeV/c. NNLO* CS model [5] for direct J/ψ production underpredicts the data, but the prediction does not include contributions from feed-down from higher charmonium states and B -hadron decays.

¹A list of members of the STAR Collaboration and acknowledgements can be found at the end of this issue.

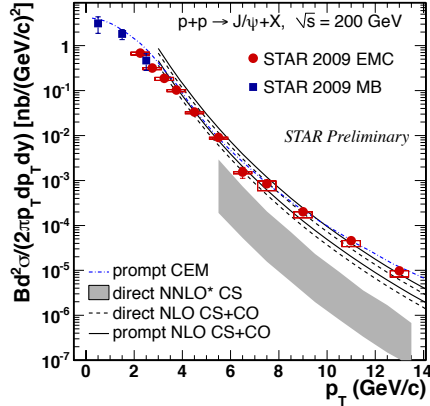


Figure 1: J/ψ invariant cross section vs. p_T in $p + p$ collisions. Blue rectangles and red circles represent low- p_T and high- p_T [2] measurements, respectively. Upper and lower curves for solid and dashed lines represent upper and lower limits of a model prediction.

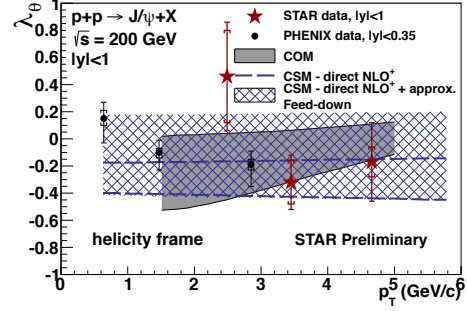


Figure 2: J/ψ polarization parameter λ_θ vs. p_T in $p + p$ collisions. Red stars represent the STAR result.

Different models of J/ψ production are able to describe the measured J/ψ production cross section reasonably well. J/ψ polarization measurement can help to distinguish among the models since they predict different dependence on p_T for the J/ψ polarization. J/ψ polarization in STAR is analyzed in the helicity frame at $|y| < 1$ and $2 < p_T < \sim 5$ GeV/c [8]. The J/ψ polarization parameter λ_θ is extracted in three p_T bins and the result is shown in Fig. 2. Within current experimental and theoretical uncertainties the obtained transverse momentum dependent λ_θ is consistent with the predictions from NLO^+ Color Singlet Model (CSM) [9] and NRQCD calculations with color octet contributions (COM) [10], and with no polarization.

3. J/ψ production in $d+Au$ and $Au+Au$ and $J/\psi v_2$ in $Au+Au$ collisions at 200 GeV

J/ψ p_T spectra in $Au+Au$ collisions for different centralities for both low and high p_T ($0 < p_T < 10$ GeV/c) are shown in Fig. 3. The obtained spectra are softer at low p_T than the Tsallis statistics Blast-wave (TBW) model prediction (dashed curves) which assumes that J/ψ flows like light hadrons [6, 7]. The data can be described by TBW fit with radial flow velocity β fixed to zero (solid curves) [7]. This could be due to a significant contribution from charm quark recombination at low p_T or small J/ψ radial flow.

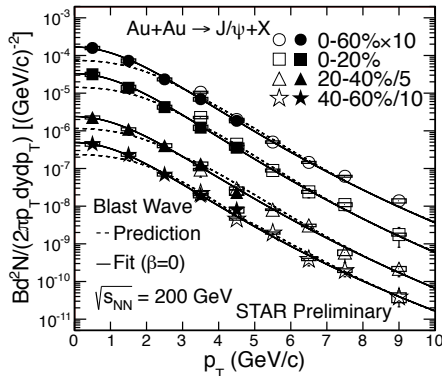


Figure 3: J/ψ p_T spectrum in $Au+Au$ collisions. Full and open symbols represent low- p_T and high- p_T [2] measurements, respectively.

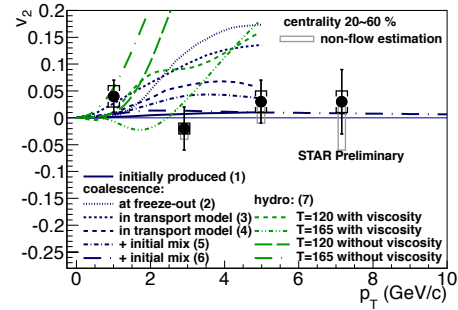


Figure 4: J/ψ v_2 vs. p_T for semi-central (20-60%) $Au+Au$ collisions with different model predictions [15]-[20].

J/ψ v_2 measurement is a crucial for testing the charm quark recombination effect. Primordial J/ψ which are produced in the initial hard scattering are expected to carry very little flow, while those that are subsequently created from the recombination of thermalized (anti-)charm quarks will exhibit considerable flow. J/ψ v_2 as a function of p_T for semi-central (20-60%) Au+Au collisions is shown in Fig. 4 with different model predictions [15]-[20]. The STAR v_2 result is consistent with zero within the errors. It disfavors the case that J/ψ is produced dominantly by coalescence from thermalized charm quarks for $p_T > 2$ GeV/c as predicted by, e.g. model (2). Models that assume only initial production of J/ψ or include both initial production and coalescence process describe the data well.

Figure 5 shows J/ψ R_{AA} in d +Au collisions as a function of N_{coll} for $p_T < 5$ GeV/c. The data are in good agreement with a model prediction using EPS09 parametrization of nuclear parton distribution functions for the shadowing and a J/ψ nuclear absorption of $\sigma_{abs} = 3$ mb [12]. The $\sigma_{abs} = 2.8^{+3.5}_{-2.6}(stat.)^{+4.0}_{-2.8}(syst.)^{+1.8}_{-1.1}(EPS09)$ mb was obtained from a fit to the data.

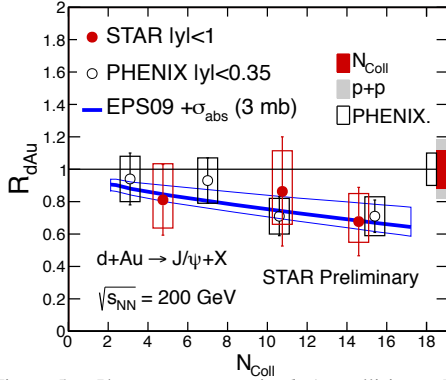


Figure 5: J/ψ R_{AA} vs. N_{coll} in d +Au collisions. Filled and open circles represent low- p_T and high- p_T [2] measurements, respectively.

J/ψ R_{AA} in Au+Au collisions as a function of N_{part} at low and high p_T [2] is shown in Fig. 6. The observed J/ψ suppression increases with a collision centrality and decreases towards higher p_T across the centrality range. At high p_T we observe suppression only for central collisions. The results are compared to two models that include primordial J/ψ production (with the color screening effect and CNM effects) and the regeneration from charm quarks [13, 14]. Low- p_T data agrees with both model predictions. At high p_T Liu et al. model [13] describes the data reasonably well while Zhao and Rapp model [14] underpredicts the R_{AA} for $N_{part} > 70$.

4. Υ production in $p + p$ and Au+Au collisions at 200 GeV

STAR has improved precision of the $p + p$ $\Upsilon(1S+2S+3S) \rightarrow e^+e^-$ cross section measurement using the 2009 data with enhanced statistics. Figure 7 shows the new STAR result as a function of rapidity with two model predictions, CEM [21] and CSM [22]. The obtained cross section is consistent with the NLO pQCD calculations.

Figure 8 shows $\Upsilon(1S+2S+3S)$ R_{AA} as a function of N_{part} in Au+Au collisions at mid-rapidity. Results are compared with two predictions of dynamic model with fireball expansion and quarkonium feed-down [23]. The calculations include variation of initial η/S and T_0 . The observed suppression at central collisions is consistent with the prediction of complete melting of 3S state and very strong suppression of 2S state from the model that uses internal energy as the heavy quark potential.

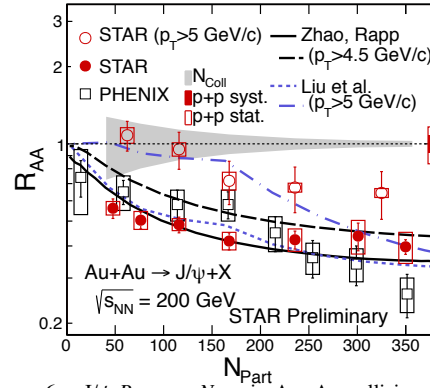


Figure 6: J/ψ R_{AA} vs. N_{part} in Au+Au collisions. Full and open circles represent low- p_T and high- p_T [2] measurements, respectively.

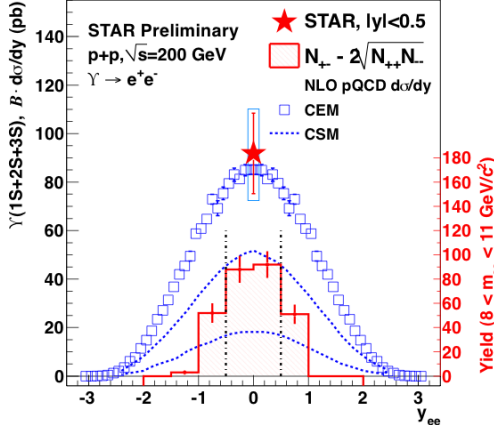


Figure 7: $\Upsilon(1S+2S+3S)$ cross section vs. rapidity in $p + p$ collisions.

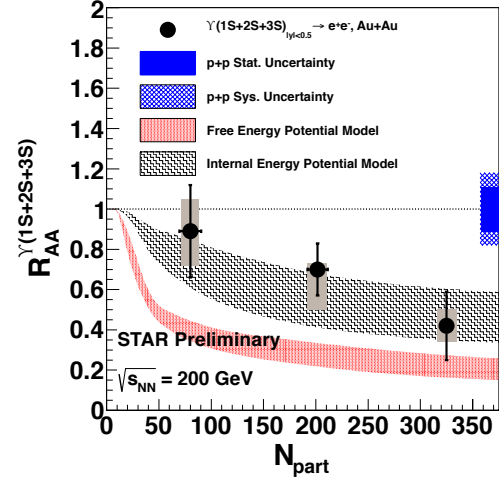


Figure 8: $\Upsilon(1S+2S+3S)$ R_{AA} vs. N_{part} in Au+Au collisions.

5. Summary

In summary, the recent results of STAR J/ψ and Υ measurements in $p + p$, $d + Au$ and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are shown. J/ψ R_{dAu} agrees with the model using EPS09 + $\sigma_{abs}^{J/\psi}$ (3 mb). J/ψ R_{AuAu} decreases with centrality and increases with p_T . At high p_T suppression is only seen in central collisions. J/ψ v_2 was found to be consistent with zero, it disfavors the case that J/ψ is produced dominantly by coalescence of thermalized charm quarks at $p_T > 2$ GeV/c. $\Upsilon(1S+2S+3S)$ Au+Au results are consistent with the model that predicts complete melting of 3S and a strong 2S suppression.

References

References

- [1] T.Matsui, H.Satz, Phys. Lett. B 178, 416 (1986)
- [2] L.Adamczyk et al., arXiv:1208.2736v1
- [3] A.D.Frawley, T.Ullrich, R. Vogt, Phys. Rept. 462, 125 (2008), and R.Vogt private communication (2009)
- [4] Y.-Q.Ma, K.Wang, K.T.Chao, Phys. Rev. D84, 51 114001 (2011), and private communication (2012)
- [5] P.Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008) and J.P.Lansberg private communication (2009)
- [6] Z.Tang et al., arXiv:1101.1912 (2011)
- [7] Z.Tang et al., Phys. Rev. C79, 051901 (2009)
- [8] B.Trzeciak (for the STAR Collaboration), Acta Physica Polonica B Proceedings Supplement Vol.5 page 549 (2012)
- [9] J.P.Lansberg, Phys. Lett. B 695, 149-156 (2011)
- [10] H.S.Chung, C.Yu, S.Kim, J.Lee, Phys. Rev. D 81, 014020 (2010)
- [11] A.Adare et al., Phys. Rev. D 82, 012001 (2010)
- [12] K.Eskola, H.Paukkunen, P.Ruuskanen, Nucl. Phys. A830, 599 (2009), R.Vogt, Phys. Rev. C81, 044903 (2010)
- [13] Y.Liu, Z.Qu, N.Xu, P.Zhuang, Phys. Lett. B678, 72 (2009)
- [14] X.Zhao, R.Rapp, Phys. Rev. C82, 064905 (2010)
- [15] L.Yan, P.Zhuang, N.Xu, Phys. Rev. Lett. 97, 232301 (2006) - J/ψ v_2 Models (1) (4)
- [16] V.Greco, C.M.Ko, R.Rapp, Phys. Lett. B595, 202 (2004) - J/ψ v_2 Models (2)
- [17] L.Ravagli, R.Rapp, Phys. Lett. B655, 126 (2007) - J/ψ v_2 Models (3)
- [18] X.Zhao, R.Rapp, 24th Winter Workshop on Nuclear Dynamics - J/ψ v_2 Models (5)
- [19] Y.Liu, N.Xu, P.Zhuang, Nucl. Phys. A834, 317 (2010) - J/ψ v_2 Models (6)
- [20] U.W.Heinz, C.Shen, (2011), private communication - J/ψ v_2 Models (7)
- [21] R.Vogt, Phys. Rep. 462125 (2008)

- [22] J.P.Lansberg, S.Brodsky, PRD 81, 051502 (2010)
- [23] M.Strickland, D. Bazow, arXiv:1112.2761v4 (2012)